

16. ALTERNATIVE GENERAL-AIRCRAFT ENGINES

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The objective of this effort is to define the most promising alternative engine (or engines) for application to general aircraft in the post-1985 time period and to advance the level of technology to the point where confident development of a new engine can begin early in the 1980's. A unified evaluation study and parametric analysis is needed of advanced propulsion concepts - alternatives to air-cooled, Otto-cycle engines - that will meet changing environmental requirements and have multifuel capability and lower fuel consumption. However, the data base necessary to accomplish the overall assessments of these engine concepts is incomplete. NASA's involvement will provide the focus (1) to obtain sufficient information to assess the many trade-offs, (2) to carry out a unified study to evaluate the suitability of alternative engines for aircraft applications and to select the most promising engine, (3) to define and carry out the most productive research and technology program for the selected engine, and (4) to assemble the pertinent technology into an experimental engine that will permit work on system technology and verify readiness for development by the aircraft engine industry. Much of this work will be done on contract.

The work will be focused on the objectives of low emissions, multifuel capability, and fuel economy. Six alternative propulsion concepts are considered to be viable candidates for future general-aircraft application: the advanced spark-ignition piston, rotary combustion, two- and four-stroke diesel, Stirling, and gas turbine engines. The first phase of the effort will be concerned with assembling an information base by means of analytical studies and experimental evaluation. This work will be done largely on contract in order to take advantage of specialized experience and capabilities. Sufficient information on each engine must be generated to allow evaluation for general-aircraft application. Design and operational characteristics - such as brake specific fuel consumption, emissions, specific weight, and so forth - must be sufficiently well defined to allow incorporation in conceptual aircraft designs for analytical evaluation of performance and other factors influencing suitability. Information derived from the NASA QCGAT program and other Lewis gas turbine technology will be used to define suitable general-aircraft turbine engine characteristics for

use in the unified aircraft systems studies. Insofar as possible, estimates will be made of the costs pertinent to each engine's development, manufacture, and operation.

Following assembly of the necessary engine characteristics data, total aircraft systems studies will be made to define the suitability of the alternative engines for general-aircraft application. It is expected that this work will be done both in-house and on contract. The results of these studies will be used to select a prime candidate engine for possible future application. Following this selection, a preliminary design of the selected alternative engine will be made in sufficient detail to characterize the engine design features and to define technology problem areas. In addition, this design will allow a better estimate of the costs involved in bringing the engine to the market. It is expected that this work will be done on contract. This contract will also include a definition of the research and technology program required to achieve the specified engine design characteristics and performance.

After selection of the most promising alternative engine, specific problems pertinent to that engine will be attacked in a comprehensive program to be carried out both in-house and on contract. The work to be done will include basic component technology - heat exchangers, seals, and so forth - component configuration, materials, manufacturing techniques, and system-related problems. This research and technology work will continue as necessary into the experimental phase. Pending the selection of that engine, a Lewis in-house, low-level, exploratory research and technology effort has begun on two contenders, the diesel and Stirling engines, about which probably the least is understood for modern aircraft use.

The research and technology effort will make possible the definition of an experimental version of the selected alternative engine. An experimental engine embodying the basic design characteristics required for aircraft application, but not to the level of refinement of a development or production engine, will be designed, built, and tested as a contractual effort extending over approximately 3 years. The design will be based on a preliminary design and on the engine research and technology done over the preceding several years. Testing will be carried out both on contract and at Lewis, with most of the latter effort coming after completion of the contractual effort. The results of this program should provide the basis for confident development of an alternative engine for general-aircraft application.

ENGINE CHARACTERIZATION PROJECTS

A good part of our effort is now directed to obtaining characteristic data for the engines of interest. The first of these is the spark-ignition piston engine.

The proposed effort can be described as follows:

- (1) Objective: To obtain characteristics data for an advanced spark-ignition piston aircraft engine for use in a unified aircraft systems study
- (2) Approach:
 - (a) Complete conceptual design of a spark-ignition piston engine incorporating existing technology not used in present engines and near-term (5 yr), low-risk technology
 - (b) Project performance, physical characteristics, and information pertinent to scaling
- (3) Effort: To be done on contract
- (4) Status: Statement of work in preparation

It may seem odd to list the spark-ignition engine as an alternative engine. However, our intent here is to use a "clean sheet" approach by designing a new engine that recognizes the existing or upcoming problems in emissions, fuel economy, and fuel availability. Furthermore, to make a fair evaluation of the potential of new alternative engine concepts, the current engine must be suitably updated in terms of technology.

A very different engine is the Stirling engine. Some of the reasons for our interest in the Stirling engine as a potential alternative aircraft engine are low emissions, low engine vibrations, fuel flexibility, and low engine noise. Emissions can be made very low, well below any projected standards, because of the continuous nature of the combustion. The nature of the engine is such that very low vibrations are experienced and the torque variation through the cycle is quite low. This should allow for significant structural weight savings and provide fatigue life margin for the propeller. The Stirling should be able to use essentially any liquid fuel with some adjustments to the combustor and fuel delivery system. In fact, any source of energy that can keep the engine hot and at operating temperature will drive a Stirling engine. The engine is also intrinsically very quiet in operation and requires no muffling.

However, the Stirling engine has a number of problems that must be solved before it can be considered for aircraft use. The most serious is probably the high specific weight (lb/hp). Substantial gains have been made in the Ford-Philips Torino engine, but substantial improvement is still required. Since the Stirling rejects about twice as much heat through its cooling system as the internal combustion engine, it requires a larger cooling system. Power control is more complicated because of the need to change the effective inventory of the working fluid to change power levels. Provision will have to be made for pressurized combustion at altitude to maintain operation. Hydrogen is the

best working fluid for performance and power output but offers significant problems in sealing and containment.

Our approach to obtaining the characteristic data for the Stirling engine is similar to that for the spark-ignition engine and is as follows:

- (1) Objective: To obtain characteristics data for a lightweight Stirling engine suitable for general-aircraft application for use in a unified aircraft systems study
- (2) Approach:
 - (a) Complete conceptual design of a lightweight Stirling engine using near-term (5 yrs), low-risk technology
 - (b) Project performance, physical characteristics, and information pertinent to scaling
- (3) Effort: To be done on contract
- (4) Status: Agreement with contractor has not yet been reached; we hope to reach an agreement in fiscal 1977.

However, the ability to develop these data is unique. Understanding of the modern Stirling engine lies today principally with Philips of The Netherlands. They have been engaged in developing the Stirling engine from a concept to a workable engine for nearly 40 years. The Ford Motor Company, which is interested in Stirling for automotive application, has contracted with Philips for an exclusive worldwide license pertinent to automotive applications. We believe, therefore, that the best source of the information for an advanced, lightweight Stirling would be Ford-Philips. A contractual agreement with them has not yet been reached, however.

The rotary engine is a relatively new concept that offers promise for aircraft application. The key characteristic of interest for the rotary engine is its low weight. Although it appears that liquid cooling is necessary, its specific weight is low even when a cooling system is included. The superior cooling potential of this liquid system, moreover, may allow leaner operation without overheating problems. This should allow reduced emissions and improved fuel utilization. The rotary engine we are examining is, in contrast to most of the other alternative engines, which are largely conceptual, a full-scale operable experimental aircraft engine. Some of the engine characteristics are water cooling (experimental), 285 horsepower, 6000 rpm, a specific weight including the radiator of 1.26 lb/hp, and a brake specific fuel consumption of 0.48 lb/bhp-hr. Our approach to the rotary engine characterization effort is as follows:

- (1) Objective: To obtain characteristics data for a two-rotor, rotary combustion aircraft engine for use in a unified aircraft systems study
- (2) Approach:
 - (a) Test engine to obtain complete performance and emissions data for an existing configuration
 - (b) Obtain physical description of engine - drawings, weight data, operational limitations, and so forth
 - (c) Obtain information that will allow analytical scaling of the engine from one-half to twice its present power
- (3) Effort: Contract with Curtiss-Wright Corporation; estimated cost, \$64,647.00; estimated period of performance, 6 months
- (4) Status: Contract awarded May 6, 1976; basic dynamometer test facility/equipment completed; engine run-in completed; emission equipment calibration and basic engine calibrations in progress; sizing parameters and engine layouts showing dimensions, configurations, accessories, and so forth, in preparation

The approach differs from that for the other engines in that actual full-scale performance and emissions data will be obtained to form the basis for all the required characteristics data. A contract is now in force with Curtiss-Wright. The engine run-in has been completed, the emissions equipment and engine calibrations are in progress, and we hope to complete the emissions and performance data within the next few months. The analytical and layout effort pertinent to engine scaling is also under way.

Diesel engines offer several attractive features for aircraft use: multifuel capability, high reliability (no mixture control, no icing problems, and no ignition problems), reduced fire and explosion hazards, and easy maintenance. The diesel has some multifuel capability, which is attractive in light of potential problems with aviation gas availability. Moreover, the lower volatility of diesel fuel would greatly reduce fire and explosion hazards. Of course, the diesel engine has proven high reliability and low maintenance in truck application. Carburetor icing and ignition problems would not exist. However, diesel engines do have some disadvantages for aircraft application: high specific weight, large volume, and negative environmental factors (noise, smell, smoke, and high hydrocarbon emissions with two-stroke machines). The most obvious disadvantage of diesels is their high specific weight. Two promising approaches to reduced weight and higher output are the turbocharged two-stroke engine and the low-compression, turbocharged four-stroke engine. Other disadvantages are less serious and can probably be alleviated through design and development effort.

We have a contract with the University of Michigan to obtain characteristics data for a low-compression, highly turbocharged four-stroke diesel engine. A primary concern with such engines is the problem of starting and low-speed operation. Their concept involves preheating the inlet air at start to allow ignition even with low compression. Their initial projections are that the specific weight of this concept will be equal to or less than a conventional spark-ignition engine. The program includes experimental and analytical effort to define the characteristics of a lightweight, low-compression diesel engine and is outlined as follows:

- (1) Objective: To obtain characteristics data for a lightweight, low-compression, turbocharged diesel engine for use in a unified aircraft systems study
- (2) Approach:
 - (a) Obtain test data on single-cylinder research engine with dieselized cylinder from standard aircraft engine
 - (b) Project characteristics of a complete aircraft diesel engine
 - (c) Design "hot-port" cylinder
- (3) Effort: Contract with University of Michigan
- (4) Status: Contract awarded June 30, 1976; single-cylinder engine being prepared

The experimental work will be done with a single-cylinder engine modified to incorporate a Teledyne Continental Motors GTS10-520 cylinder converted to diesel operation. Tests will be made to define the optimum combination of compression ratio, inlet air temperature, and pressure. Performance will be determined for the optimum combination, and full-scale engine characteristics will be derived analytically from those data.

The two-stroke diesel engine intrinsically has a potential for high power output. Preliminary data on the McCulloch engine, which has a unique patented combustion chamber, indicate high specific output, high efficiency, and smooth operation. The engine has not yet been tested to full power. Our intent is to do so and to fully characterize the engine for input to our overall alternative engine comparison study. The planned approach is as follows:

- (1) Objective: To obtain characteristics data for a two-stroke diesel engine for use in a unified aircraft systems study

(2) Approach:

- (a) Test McCulloch engine to obtain complete performance and emissions data for existing configuration
- (b) Obtain physical description of engine - drawings, weights, operational limitations, etc.
- (c) Obtain information to allow analytical scaling of the engine from one-half to twice its present power

(3) Effort: To be performed on contract

(4) Status: Agreement with contractor has not yet been reached; we hope to arrange for engine testing in fiscal 1977.

Some characteristics of the McCulloch engine are its experimental two-stroke design, 180-cubic-inch displacement, 180 horsepower, 2850 rpm, and high supercharging. It has been tested to 64-percent power, is equivalent to a naturally aspirated GTSIO-520 engine, and has a high-turbulence combustion chamber design.

Gas turbine engines for application to general aircraft will be examined in both turbofan and turboprop versions:

- (1) Objective: To obtain characteristics data for a turboprop and turbofan engine suitable for general-aircraft application in a unified aircraft systems study

The approach is as follows:

- (2) Approach: To use data from the QCGAT program and other Lewis Research Center gas turbine technology to define performance and physical characteristics
- (3) Effort: To be performed in house
- (4) Status: In planning stage

Data for characterization of small gas turbine engines for general aircraft will be obtained largely from the QCGAT program and other Lewis programs related to gas turbine technology. The specific conceptual designs and their characteristics will be developed at Lewis.

All the engine characteristics data obtained in these engine studies will be applied to an aircraft systems study. The project is as follows:

- (1) Objective: To examine the candidate alternative engines to define the most promising engine (or engines) for general-aircraft application in the post-1985 period

(2) Approach:

- (a) Correlate the material obtained from the six engine characterization studies
- (b) Use engine data in analytical aircraft design and evaluation program to define best engine candidate for future application

(3) Effort: Both in-house and on contract

(4) Status: In planning stage for fiscal 1977

Performance specifications for a typical single-engine unpressurized airplane and a twin-engine pressurized airplane will be used as the base to develop conceptual aircraft designs to match each of the candidate powerplants. Appropriate missions will be examined analytically and the significant performance differences determined. Cost, both initial and continuing, will also be examined as a significant factor in comparing the engines. It is intended that this work will be done both in-house and on contract. This work in combination with the engine characteristics studies should provide the basic information that will allow us to make the appropriate comparisons and trade-offs and to select the most promising engine for future research and technology concentration.

IN-HOUSE RESEARCH AND TECHNOLOGY

The in-house work currently in progress is focused on two promising engines that have not been examined extensively for aircraft application - the Stirling and diesel engines. As discussed previously, our principal goals in diesel engines are to reduce specific weight and to increase specific power. The primary focus of our effort will be on low-compression, highly turbocharged, four-stroke diesel engines. This is similar to the work being done at the University of Michigan in that the principal problem lies in developing an acceptable system for starting and low-speed operation. Our approach, as shown in figure 16-1, is different:

- (1) Objective: To develop technology for diesel engines that will permit substantial improvement in specific weight and power and further reduce fuel consumption and exhaust emissions

(2) Approach:

- (a) Analyze highly turbocharged, low-compression-ratio diesel engine system with low-speed turbine augmentation to facilitate start and low-speed operation; define potential performance and technology problem areas

- (b) Purchase and install a single-cylinder diesel research engine that will be used to test the concepts defined in the analysis
 - (c) Experimentally test key components such as the low-speed turbine augmentation combustion system
 - (d) Experimentally examine the possibility of reducing oxides-of-nitrogen(NO_x) emissions by introducing high-latent-heat fluids such as water or methanol
- (3) Status: Preliminary system analysis complete; test cell being prepared; single-cylinder research engine built and acceptance test scheduled; combustion system in test

Instead of heating the inlet air, we propose to use a semi-independent turbocharger to provide higher engine inlet flows and pressures at start. The basic new element in the system is a catalytic combustor that can provide turbine-drive gas even when the diesel engine is not operating. During full-power operation, the diesel exhaust would be routed through the catalytic combustor, but no fuel would be added. This should provide for cleanup of any hydrocarbons in the diesel exhaust before release to the atmosphere. A single-cylinder AVL research diesel engine has been purchased and is now ready for acceptance testing. This will serve as the primary test bed for defining the design parameters of the low-compression semi-independent turbocharged diesel engine. The combustion system will be tested and developed separately before combining it with the engine system. We also plan to examine the effect of additions such as water or methanol on NO_x formation. Proper introduction of these high-latent-heat fluids, either mixed with the fuel or separately introduced, may lower peak combustion temperature and hence NO_x production without reducing efficiency significantly.

Our Stirling engine technology program is outlined as follows:

- (1) Objective; To become familiar with Stirling engine concepts, determine technology needs, and define a pertinent research and technology program
- (2) Approach:
 - (a) Obtain Stirling-type engine for test
 - (b) Develop computer models for engines
 - (c) Test engines to define performance and control characteristics and to calibrate and verify computer programs
 - (d) Define desirable component characteristics and begin work on component technology

- (2) Status: Helium performance tests complete on 8-hp rhombic-drive engine (GMC-GPU3); engine being reconditioned in preparation for hydrogen tests; NASA computer simulation being revised to include effects of mechanical friction and seal leakage; 6-kW, free-piston engine has not yet achieved rated power; contractor will perform a detailed analysis to define the problem and determine a solution

Our primary objectives are to become familiar with Stirling engine concepts, to determine the technology needed to bring the concept to maturity for aircraft application, and to define a research and technology program that fulfills these needs. Our first step in this effort was to obtain appropriate Stirling engines for testing. Concurrently, we worked on the assembling of computer engine simulation models for these engines. Our plans are to test the engines over a wide range of operating parameters and to compare the results with those obtained from the engine simulation program. The intent is to use these data to develop, verify, and calibrate computer simulations that will correspond accurately to the actual engines. As we gain confidence in our ability to simulate the engines and in our understanding of component behavior and cycle relationships, we will begin work on advancing component technology.

We have on hand two GMC-GPU3 Stirling engines, which are rhombic-drive machines rated at about 8 horsepower. One has been refurbished and tested to obtain performance data with helium working fluid. This engine is now being reconditioned in preparation for tests with hydrogen working fluid. The other engine will require extensive refurbishment before testing. We have also contracted for a 6-kilowatt, free-piston Stirling engine, which we plan to use in extending our understanding. The engine has been designed and fabricated and set up for acceptance testing. It has not yet been able to achieve rated power. The reasons for this deficiency are not clear. The contractor will perform a detailed analysis using his newly developed proprietary simulation program in order to define the problem and determine a solution.

SUMMARY

In summary, the overall objective of the program is to determine which alternative engines are most promising for possible future application, to define the research and technology program required to bring them to the required state of maturity, and to carry out that program. Our approach includes both in-house and contractual effort and both analytical and experimental work. It involves generating the required characteristics data for candidate engines and applying these data to an overall aircraft-mission study to define the most promising engines. In addition, the required research and technology program for the selected engine will be defined and implemented. The overall program is progressing about as planned; both in-house and contractual efforts are well under way - with some exceptions as noted previously.

DISCUSSION

Q - F. Riddell: Why do you continue to talk about seal problems with the Stirling engine? Aren't 10 000 hours of service life enough?

A - W. Tomazic: Seal life has to be proven over a longer period of time with more engines. We are having seal problems in testing our engines. People are concerned about high-pressure hydrogen stored in the engine and so forth. There is still some question about the proprietary coating process that Phillips uses to prevent hydrogen diffusion. The problem still seems to exist.

COMMENT - F. Riddell: Part of the hydrogen problem was settled as a result of Ford's requirements, you know. Ford requires that there be no hydrogen addition in 50 000 miles. They also require going from idle to 90 percent of full load torque in 0.6 second. Neither of those requirements would apply to an aircraft engine.

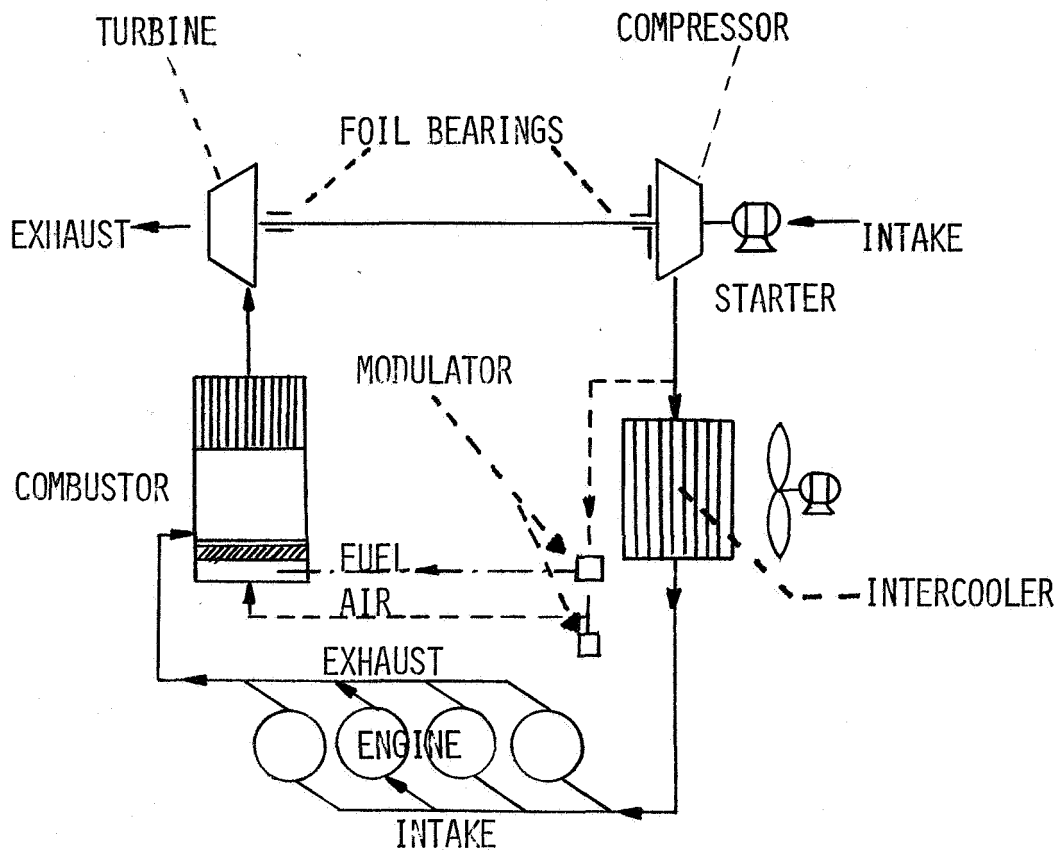
COMMENT - W. Tomazic: No, I agree the design requirements are quite different. That is one of the reasons we would like to look specifically at the aircraft engine. As far as seals are concerned, a good deal of development is still required. Roll-sock seals are not wholly satisfactory, primarily because of the complicated pressure regulation system required to prevent overloading the seal. If the roll-sock seal fails, the failure is catastrophic. Sliding seals are being looked at again.

COMMENT - F. Riddell: I saw the sliding seals. Phillips has done quite a bit of work on them and gotten good service life. It is a Teflon type of dry seal with liquid cooling on the outside of the cylinder. There is little friction or frictional loss from the seals. They do receive some heat from the cylinder barrel, so Phillips cools them. The seals have been working very nicely according to the people at Phillips.

Q - C. Rembleske: I know that Cessna has flown a rotary engine. What have they actually done in rotary engine research?

A - H. Nay: Approximately 4 1/2 years ago the Curtis-Wright, two-chamber, 185-horsepower automotive engine was tested in a Cessna Cardinal with a two-stage reduction gear system. This was a 5000-rpm engine with a propeller rpm of about 2200. This program was part of the quiet engine program. The engine had a very massive exhaust muffler system. After a great many hardware difficulties, the aircraft was successfully flown. It is basically a four-place aircraft carrying 50 gallons of fuel, which gave it about 5 hours of cruise endurance. The water-cooled engine and that particular two-stage reduction gear system resulted in basically a one-place aircraft with test instrumentation and a moderate amount of fuel on board. It was also tested in another configuration in a joint program with Curtis-Wright. The first program was sponsored by the Navy with NASA involvement. The second program was a joint program between Curtis-Wright and Cessna and was aimed at a more practical evaluation of the aircraft. A single-stage reduction system was used with the propeller rpm at 2700, which was the rpm of the basic

Cardinal airplane with the O-360 Lycoming carbureted 180-horsepower engine. The engine did not develop the full 185 horsepower. The best result, as I recall, were 155 to 160 horsepower. The aircraft provided demonstration rides for a number of us, as a two-place aircraft with considerable degradation in takeoff and climb performance. The general conclusion was that the level of aircraft engine technology was very definitely not acceptable. An electronic ignition system was used and proved extremely troublesome. It resulted in two forced landings before we finally got it working satisfactorily. Nothing that I can say here could give any definitive conclusions on the long-term viability of the rotary combustion aircraft engine. Without qualification, that engine as tested was operationally unsatisfactory and totally unacceptable from a weight and performance standpoint.



EXHAUST PRODUCTS + AIR + FUEL (AS REQUIRED) INTO CATALYTIC COMBUSTOR

- PRODUCES DRIVING GAS FOR TURBINE
- CLEANS UP HC IN EXHAUST
- ALLOWS HIGH POWER FROM LOW CR ENGINE

Figure 16-1